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Agricultural Memorandum No 889

The dependence of Potential Transpiration on Temperature, Windspeed, Vapour Pressure and Sunshine Duration

by M Field

1. Introduction

The purpose of this paper is to investigate the effect on Potential Transpiration of varying independently the temperature, windspeed, vapour pressure and duration of sunshine at various times during the year.

2. The Transpiration Algorithm

The variables that figure in the transpiration algorithm in addition to the meteorological parameters mentioned above are,

- (a) The Cowley coefficients a, b
- (b) The ground heat flux, G
- (c) The long wave correction term, B
- (d) The stomatal resistance, r_s
- (e) The daylength, N
- (f) The short wave radiation incident on the 'top of the atmosphere', R_a

(see Appendix for details)

$$PT = \frac{\Delta (RNS - RNL - G) + 0.429(1 + \text{Wind}/100)(SVP - VP)}{\Delta + 0.66(1 + r_{sa})} \quad \text{in mm/day}$$

where RNS = short wave radiation = $R_a (1 - \text{alb})$ (Cowley), in mm/day

alb = short wave albedo = 0.25

Cowley = $(a + b \cdot n/N)$, where $a = 0.23$

RNL = nett long wave radiation

$$= 1.88 \times 10^{-9} B(T+273)^4 (0.56 - 0.08 \sqrt{VP}) (0.1 + 0.9n/N), \text{ in mm/day}$$

n = sunshine duration, in hour

T = air temperature, in $^{\circ}\text{C}$

VP = vapour pressure, SVP = saturated vapour pressure, in mb

Wind = run of wind, in miles/day

Δ = slope of SVP curve in $\text{mb}/^{\circ}\text{C}$

$r_{sa} = r_s/r_a$, where $r_a = 100/(1 + \text{wind}/100)$, in s/m

For a discussion of the aerodynamic term r_a see Agricultural Memorandum No. 862.

3. Approach to the analysis

The Potential Transpiration was calculated for each month during the year using monthly means of vapour pressure (VP), sunshine (SS), temperature (T) and windspeed (W) with the appropriate values of G, B, b, r_s , and N and R_a (see Appendix). The standard deviations, σ , of the four meteorological parameters were calculated for each month; these give an estimate of the typical variation to be expected during the month. An alternative scheme, to select a variation of $\pm n\%$, is less suitable, the standard deviation of the parameters differs from one to another and changes during the year. For example a mean vapour pressure in January of 7.0mb with a σ of 1.9mb corresponds to a change of 27% compared to 15% in August with $\sigma = 2.1$ mb and a mean vapour pressure of 14.2mb.

It is important to realize,

(i) that in varying independently the windspeed, vapour pressure, temperature and sunshine duration one occasionally simulates unrealistic meteorological conditions. For example when the vapour pressure is increased or the temperature is decreased it is possible for the vapour pressure deficit to become negative. This occurred between the months October to February inclusive; the vapour pressure deficit was set to zero to avoid super-saturation.

(ii) that the cross-correlations between the meteorological parameters have not been considered.

4. Applications of Results

Some suggested applications for the graphs in Figures 1, 2 and 3 follow,

(a) to compare the relative importance of the aerodynamic and radiation terms in contributing to the PT.

(b) to investigate the effect of introducing errors into the meteorological parameters.

For example,

(i) when comparing the windspeed as estimated by MORECS with the measurement taken on a 2m mast it was found that the latter was 3 knots lower on average. To make a quick estimate of the significance of this difference see the graph for June. The PT would have been underestimated by about 0.35 mm/day using the 2m mast, this corresponds to a 10% reduction in PT.

(ii) If the air temperature were measured at say 100m rather than at sea level we would expect the PT at sea level to be underestimated. By increasing the temperature by 0.6°C we increase the PT by 0.2mm/day in June, this corresponds to a change in PT of 6%. (but see comment 3 (ii)).

(iii) under light wind conditions the vapour pressure can be overestimated if the wet bulb is poorly ventilated.

(c) to investigate the possibility of using monthly mean values of meteorological parameters for making quick 'back of an envelope' estimates of PT.

(d) to find the parameters which have greatest effect on the PT at various times of the year.

5. Meteorological Data

Meteorological data were selected from the synoptic station at Watnall in Nottinghamshire. The mean and standard deviations of sunshine, vapour pressure,

temperature and windspeed were obtained over the period 1/1/59 to 31/12/78

The windspeed was measured at 10 m and 'reduced' to 2 m using the neutral stability approach, viz.

$$u(z_2)/u(z_1) = \ln(z_2/z_0) / \ln(z_1/z_0)$$

where $u(z)$ = windspeed at height z

putting $z_0 = 1$ cm, suitable for a short crop, we find $u(2 \text{ m}) = u(10 \text{ m}) \times 0.77$.

6. The Results (see enclosed graphs)

The y-axis is the Potential Transpiration in mm/day. The x-axis is wind-speed (W) in miles/day, temperature (T) in °C, vapour pressure (VP) in mb or sunshine (SS) in hours/day. The PT calculated from the monthly means of the four parameters corresponds to the point mid-way along the x-axis. The points to the left and right are at $\pm \sigma$ for each of the parameters. For example the PT in June was on average 3.5 mm/day. This corresponds to $WW=164$ miles/day, $T=14.3^\circ\text{C}$, $VP=12.4$ mb, $SS=6.4$ hr/day. If we increase the temperature by σ to 17.1°C , keeping the other parameters constant, then the PT increases to 5 mm/day.

The stripes beneath the intersection of the curves indicate the contribution to the mean value of the PT by the aerodynamic term (open stripe) and radiation term (black stripe).

7. Some comments on the results

(a) The percentage changes in PT when the meteorological parameters are set to their values at $\pm \sigma$ were greatest in the winter months (see Fig 3). Temperature and vapour pressure behaved similarly as did the sunshine duration and windspeed.

(b) The absolute value of PT was more strongly dependent on temperature and vapour pressure than on windspeed and sunshine duration (see Fig 2). This dependence was greater in the summer than the winter.

(c) The correlation between sunshine duration and PT was negative in the months October to March inclusive (see Fig 1). At this time of year the nett long wave radiation was more strongly dependent on the sunshine duration than the short wave radiation.

(d) The Radiation term was very small and negative from November to February inclusive (see Fig 1 and Appendix)

8. Concluding Remark

The point which emerges most clearly is that the vapour pressure deficit strongly influences the PT at all times of the year. It is therefore most important to make careful estimates of the magnitude of this term when making calculations of PT.

Any comments or suggestions on this paper should be referred to the author.

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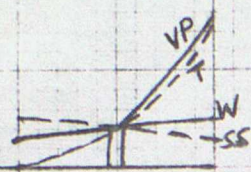
References

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|-------------|------|---|
| Cowley, J P | 1978 | The distribution over Great Britain of global solar irradiation on a horizontal surface. Met. Mag. 107, pp 357-373. |
| Thompson, N | 1979 | Agricultural Memorandum No 862. |

Acknowledgment To Mr I Barrie for extracting the synoptic data.

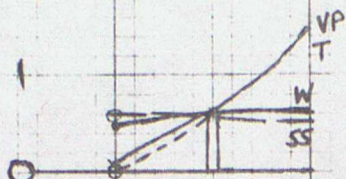
FIG. 1

JAN



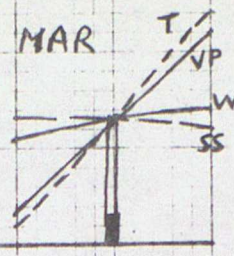
(W)	111	198	285
(T)	0	3.3	6.6
(VP)	8.9	7.0	5.1
(SS)	0	1.3	3.2

FEB



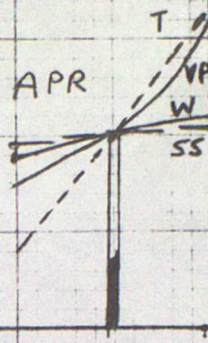
(W)	102	183	264
(T)	0.3	3.4	6.5
(VP)	8.6	6.9	5.2
(SS)	0	1.7	4.0

MAR



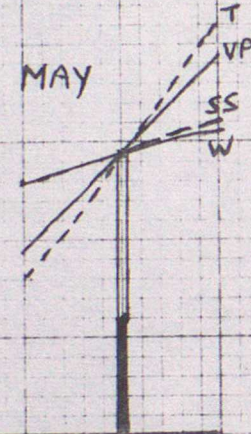
(W)	119	198	277
(T)	2.4	5.3	8.2
(VP)	8.9	7.3	5.7
(SS)	0	2.9	5.9

APR



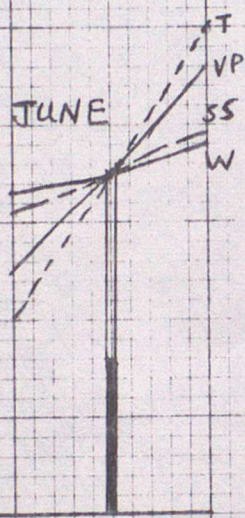
(W)	124	196	268
(T)	4.9	7.7	10.5
(VP)	10.3	8.4	6.5
(SS)	0.4	3.8	7.2

MAY



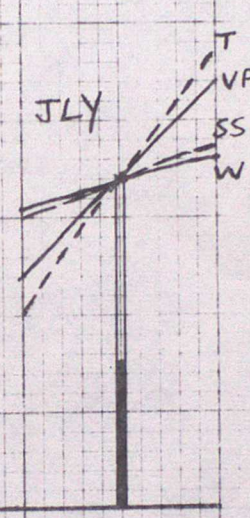
(W)	109	181	253
(T)	8.5	11.1	13.7
(VP)	12.1	10.2	8.3
(SS)	1.0	5.3	9.6

JUNE



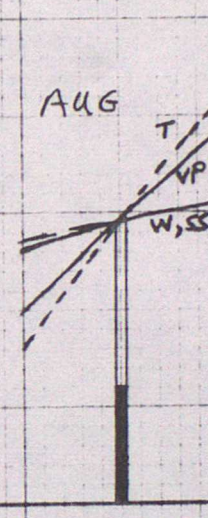
(W)	111	164	217
(T)	11.5	14.3	17.1
(VP)	14.7	12.4	10.1
(SS)	1.7	6.4	11.1

JLY



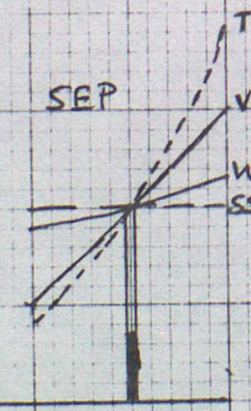
(W)	98	156	214
(T)	13.2	15.7	18.2
(VP)	16.1	13.8	11.5
(SS)	1.0	5.1	9.2

AUG



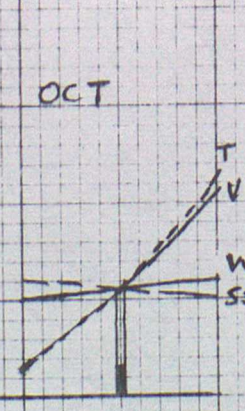
(W)	91	149	207
(T)	13.1	15.6	18.1
(VP)	16.3	14.2	12.1
(SS)	1.0	5.0	9.0

SEP



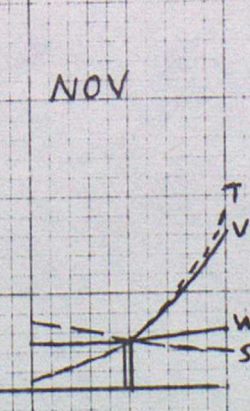
(W)	84	159	234
(T)	11.0	13.4	15.8
(VP)	10.6	12.8	15.0
(SS)	0.5	3.8	7.1

OCT



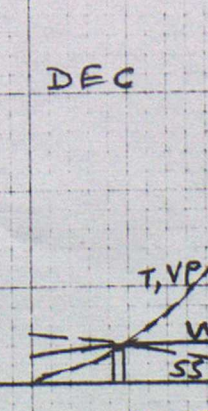
(W)	96	166	236
(T)	7.7	10.4	13.1
(VP)	8.7	11.0	13.3
(SS)	0	2.6	5.3

NOV



(W)	113	192	271
(T)	2.9	5.9	8.9
(VP)	6.2	8.3	10.4
(SS)	0	1.8	4.1

DEC



(W)	104	189	274
(T)	0.6	3.8	7.0
(VP)	5.3	7.3	9.3
(SS)	0	1.3	3.1

FIGURE 2

Change in PT in mm when a met-parameter is changed
by 1 standard deviation from its mean value

we define, $\text{change in PT} = \frac{1}{2} |PT(\text{mean} + \sigma) - PT(\text{mean} - \sigma)|$

change in PT/mm day⁻¹

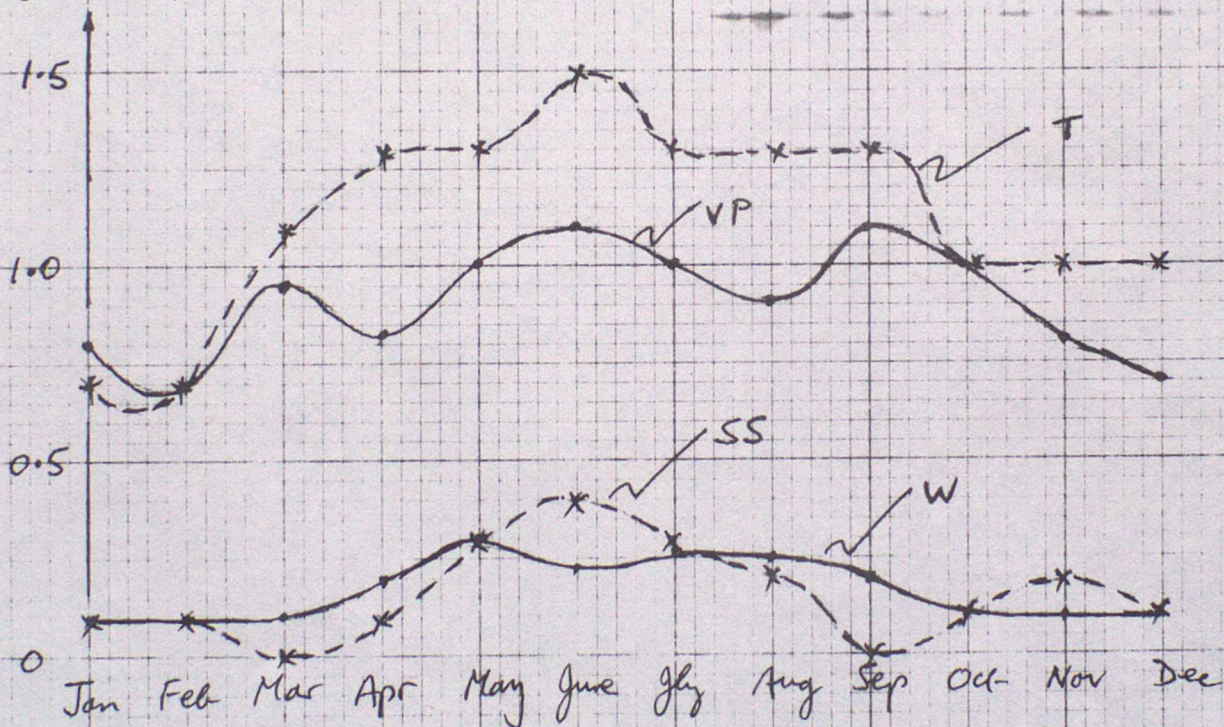
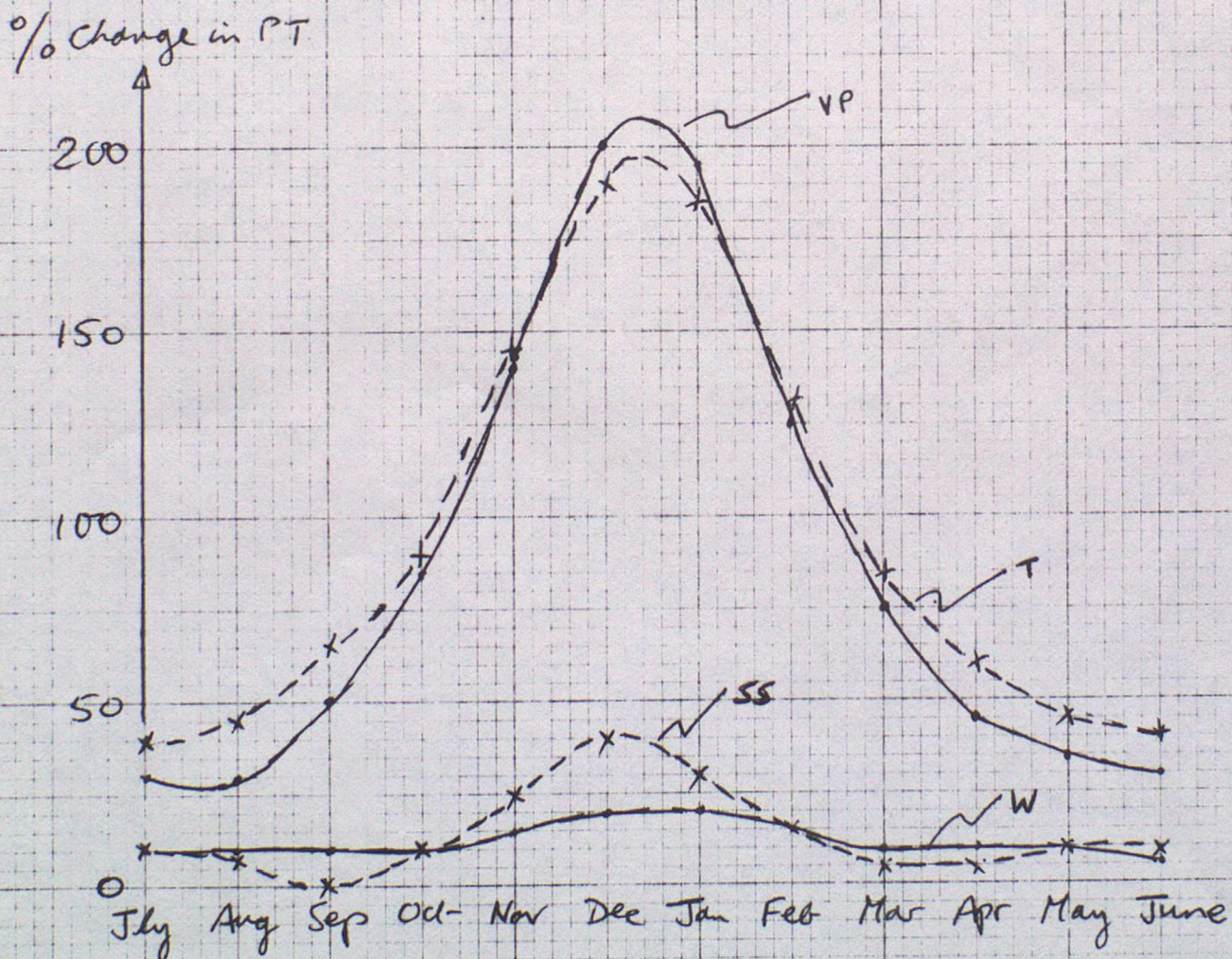


FIGURE 3

% change in Potential Transpiration when a
met parameter is changed by one standard
deviation from its mean value

we define, % change in PT = $\frac{1/2 | PT(\text{mean} + \sigma) - PT(\text{mean} - \sigma) |}{PT(\text{mean})} \times 100\%$



Appendix Monthly PT and the parameters used in PT calculation.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
PT (mm/day)	0.41	0.56	1.26	2.02	2.91	3.54	3.39	2.88	2.03	1.11	0.58	0.37
Aerodynamic Term	0.43	0.50	0.99	1.36	1.73	1.97	1.92	1.64	1.33	0.83	0.54	0.41
Radiation Term	-0.02	0.06	0.27	0.66	1.18	1.57	1.47	1.24	0.70	0.28	0.04	-0.04
N (hr)	8.0	9.8	11.6	13.7	15.4	16.5	16.1	14.5	12.5	10.6	8.6	7.6
Ra (mm/day)	3.0	5.3	8.6	12.5	15.6	17.2	16.6	14.0	10.3	6.6	3.7	2.5
G (mm/day)	-0.2	-0.01	0.04	0.24	0.34	0.37	0.31	0.10	-0.12	-0.30	-0.37	-0.30
B	1.04	1.06	1.09	1.12	1.16	1.17	1.18	1.17	1.16	1.12	1.08	1.05
rs (s/m)	50	50	40	30	30	30	30	30	30	40	50	50
Cowley coeff, b	0.42	0.49	0.52	0.53	0.55	0.52	0.50	0.49	0.48	0.47	0.47	0.45